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## Quarterly Technical Summary

### Advanced Electronic Technology

15 August 1977

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**Lincoln Laboratory**

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS



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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

*Raymond L. Loiselle*  
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LINCOLN LABORATORY

ADVANCED ELECTRONIC TECHNOLOGY

QUARTERLY TECHNICAL SUMMARY REPORT  
TO THE  
AIR FORCE SYSTEMS COMMAND

1 MAY - 31 JULY 1977

ISSUED 23 SEPTEMBER 1977

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## INTRODUCTION

This Quarterly Technical Summary covers the period 1 May through 31 July 1977. It consolidates the reports of Division 2 (Data Systems) and Division 8 (Solid State) on the Advanced Electronic Technology Program.

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DATA SYSTEMS  
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 May through 31 July 1977 on Data Systems. Separate reports describing other work of Division 2 are issued for the following programs:

Seismic Discrimination	ARPA/NMRO
Distributed Surveillance Networks	ARPA/IPTO
Education Technology	Bureau of Mines, ARPA/HRRO
Network Speech Processing	OSD-DCA
Digital Voice Processing	AF/ESD
Packet Speech	ARPA/IPTO
Communications Adaptive Internetting	ARPA/IPTO
Radar Signal Processing. Technology	ARMY/BMDATC
Nuclear Safety Designs	NRC

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DIGITAL COMPUTERS  
GROUP 23

I. INTRODUCTION

Poly-ox fabricated serial-to-parallel converter operation has been increased to 750 MHz. Design has been completed of a 65-kbit partially decoded MNOS memory chip. Implanted neon has been used to create electrical isolation for planar MNOS memory arrays. Techniques for plasma etching Al and Al-Si-Cu with high resolution and uniformity have been developed.

II. APPLICATIONS

A. Serial/Parallel Converter

Two additional runs of poly-ox isolated 8-bit Serial/Parallel (S/P) converter wafers, having progressively shallower base implants at 125 and 100 keV, have been processed through wafer test, packaging, and performance testing. S/P converter devices from these runs shifted an alternate one-zero pattern at 550 and 600 MHz, respectively. Single flip-flops in evaluation circuit devices from these runs operated correctly at clock rates to the 1-GHz limit of the test system.

Measurement of on-chip waveforms using a diagnostic microprober shows the converter circuit shift rate to be limited by the on-chip clock-line transition times. A modified converter circuit metallization has been designed which has a faster clock driver circuit. One run of wafers with 125-keV base implants using this new metallization yielded converter devices which operate correctly to 750 MHz. Microprobing indicates that the circuit is still limited by on-chip clock waveforms.

Redesign work, using both circuit simulation and experimental wafer fabrication, is focused on improving clock-line waveforms.

B. MNOS Capacitor Memory

A preliminary mask set and fabrication process has been designed for a partially decoded 65K MNOS capacitor memory. An MOS transistor circuit having one transistor and resistor per row and per column of the array is used to perform a first-level decoding operation on-chip. The chip has 68 bonding pads leading to the final decoding operation which is performed off-chip. Storage sites are on 0.4-mil centers, and the overall chip dimensions are approximately 220  $\times$  220 mils. The fabrication process requires 12 mask steps, of which only three require fine pattern definition, and two require critical alignments.

Two process improvements currently under investigation for the MNOS capacitor memory are: (1) the use of amorphous Si as created by neon implantation to isolate Si digit lines while leaving a planar Si surface, and (2) the use of an implanted As buried layer to eliminate both vertical and lateral autodoping during epitaxial growth.

C. 16-  $\times$  16-Bit ECL Serial Multiplier (MUDPAC)

Logical and circuit design is in progress on a 16-  $\times$  16-bit high-speed multiplier to be fabricated by the poly-ox process. It will employ roughly 3000 transistors. The device, named MUDPAC (Multiplier with Double Precision Accumulator), will be capable of multiplying two

16-bit, 2's-complement numbers, presented one-at-a-time on a 16-bit input bus, to form a 32-bit, 2's-complement product available 16 bits at a time on the output bus. The MUDPAC will also be able to accumulate sums of such products up to 40 bits, a feature very useful in operations such as digital filtering and correlating. The processing will be done within the chip as a serial addshift multiply with saving of carries. The carry-saving feature will necessitate 40 clock pulses, generated by an on-chip oscillator, to complete a multiply-and-accumulate operation, but will need only a single gate delay between clocks, since no time will be required for propagating carries. The design value for the clock period is 2.0 nsec maximum, which means that a multiply will be performed in 80 nsec or less.

The logic design for the MUDPAC is virtually complete. The circuit logic is being simulated with the GPSS programming language. The individual gates are represented as ideal logic functions with delays. Once this simulation (now about 1/3 done) is completed, it will be possible to develop a wafer test program on the simulator, eliminating the step of building an MSI hardware simulator, as was done for each gate array chip.

Smaller portions of the MUDPAC, such as the on-chip 500-MHz oscillator and 1 bit of the main adder, are being simulated at the transistor level using the SPICE programming language. An oscillator has been designed in this way that is capable of being regulated between 200 and 700 MHz with an off-chip resistor that controls the pulldown current of two emitter followers on the chip. The oscillator will be started by an external clock signal and turn itself off after 40 clocks via an on-chip counter. This scheme avoids the time-consuming synchronization of a free-running, on-chip oscillator with a transition of a slower off-chip clock. Simulation of the basic adder logic with SPICE indicates that it can be driven at the 500-MHz design frequency. Further simulation is being done to determine the limits of the adder speed.

Work has begun on the layout of the basic parts of the MUDPAC, with a view toward laying out a test chip. The test chip will probably include the oscillator, a heavily loaded clock driver, and a bit or two of the adder, as well as subcircuits of these three.

### III. IC PROCESSING

#### A. Poly-Ox Isolation

An ion-implanted arsenic buried-collector has been incorporated into the poly-ox process. This procedure yields a silicon surface of much higher quality for subsequent silicon epitaxy growth than does the arsenic spin-on glass method. Another improvement is the use of a recessed oxide spoiler layer under the polysilicon. This reduces the epi-poly step height, improves epi-isolation characteristics, and increases oxide spoiler thickness which can reduce parasitic capacitance.

A further modification of the poly-ox process is the inclusion of a backside ohmic contact to the silicon substrate. This can be accomplished either by forming a silicon-gold eutectic or by heavily implanting the back side with a shallow dose of boron, annealing and metallizing with Al-Si-Cu.

#### B. Self-Aligned Transistors

Double-implanted, self-aligned, NPN, bipolar transistors have been fabricated with thinner basewidths thereby increasing  $f_T$  to the 5-GHz design goal. Attention is now focused on improvement in yield by reduction of emitter-base and emitter-collector leakages, and tighter distributions of parameters.

### C. Photolithography and Plasma Etching

An automatic photoresist developing and rinse system has been installed in order to eliminate operator-caused variations.

A plasma-etching reactor for aluminum and Al-Si-Cu has been constructed to a design based on a considerable number of etching experiments. This system incorporates a planetary wafer holder plus gas-flow and electric-field compensation to produce very uniform, repeatable etching of Al and Al-Si-Cu. Since the plasma does not affect the photoresist, "knee breakdown" is eliminated, undercutting is greatly reduced, and patterning of small geometries is extremely uniform from wafer to wafer and within a wafer for linewidths from 10 to 1  $\mu\text{m}$ .

### D. MOS Transistors

P-channel MOS transistors were fabricated to provide design information on address selection transistors for an MNOS memory array. The selection scheme requires transistors with breakdowns exceeding 35 V and with conductance in the linear region exceeding 1.5 mmhos. To achieve adequate breakdown voltages, the source and drain diffusions will be 1  $\mu\text{m}$  deep which is the epi thickness; a 1- $\mu\text{m}$  buried N region will be used to extend the combined epi and N region thickness to 2  $\mu\text{m}$ . To achieve 1.5-mmhos conductance, the design includes a 1000- $\text{\AA}$  gate oxide, epi doping of  $1 \times 10^{16}$  phosphorous atoms/cm<sup>3</sup>, and a channel width-to-length ratio of 18.

### E. I<sup>2</sup>L

I<sup>2</sup>L circuits are in fabrication with high-conductivity NPN extrinsic bases for high fanout. A very simple oxide-isolated ion-implanted processing scheme has been designed.

### F. ECL Processing

Ion implantation of arsenic is being studied in order to eliminate the surface damage resulting from the use of the arsenosilica spin-on film. High-quality epitaxial films were grown on gate array wafers whose subcollectors were formed by a dose of  $5 \times 10^{15}$  arsenic ions/cm<sup>2</sup> implanted at 50 keV and annealed in oxygen at 1250 °C for 90 min.

An improvement in the quality of epitaxial films deposited during periods of high relative humidity was achieved by adopting a slow heatup cycle to drive off additional moisture from the susceptor and wafers. This modification resulted in a significant reduction in fine etch pits, defects characteristic of films grown in humid weather.

## IV. DESIGN, ANALYSIS, AND TESTING

### A. MNOS Tester

During this quarter, the logic circuitry for the MNOS memory tester was built. The tester is capable of addressing a 32 × 32 array and supplying the appropriate TTL levels for the analog switches. The system is being upgraded in order to test the 65K memory chip.

### B. MNOS Sense Circuits

A special low-noise discrete op amp was designed for observing C-V curves which reduced the noise by at least a factor of two. A synchronous clamp circuit has been built which effectively subtracts the varying value of  $C_0$  (selected-bit base value and parasitic capacitance) from the incoming signal.

### C. Modeling High- and Low-Conductivity Nitride Films

The modified Svensson model for nitride conductivity described in the 15 May 1977 Quarterly Technical Summary was developed to explain the conduction mechanism in low-conductivity nitride. In the low-conductivity case, it was found that the donor trap density was in excess of the acceptor trap density by about 10 percent. However, if it is assumed that the acceptor traps are in excess by some 15 percent, the values of conductivity calculated from the model are of the same order of magnitude as the measured values of high-conductivity nitride films.

Nitride conductivity is varied by controlling the amount of hydrogen present during Chemical Vapor Deposition (CVD). By assuming that the ratio of donor-to-acceptor traps is determined by the amount of hydrogen present during the growth of the nitride films, the modified Svensson model can be used to explain both high- and low-conductivity nitride films.

### D. Poly-Ox Device Simulation Parameters

Complete data on transistors and device parasitics from one run of the poly-ox isolated S/P converter have been obtained for use in SPICE simulation. Transistors with 100-keV base implants have peak measured  $f_T$  of approximately 4.0 GHz at  $V_{CB} = 0$  V, and 5.0 GHz at  $V_{CB} = 3$  V. First-level metal wiring capacitance to the substrate is  $0.015 \text{ pF}/\text{mil}^2$ , about 1/3 the value on conventional gate-array chips. This low value is due to the thick field oxide insulation provided by the poly-ox process.

### E. Diagnostic Probe

A high impedance probe to permit measurement of internal signals of packaged integrated circuits operating at full speed has been built and is now serving as a powerful diagnostic tool. The probe consists of a commercial active oscilloscope probe mounted on a 3-axis manipulator, with a capacitively coupled probe tip to make contact to IC top-level metal. Input capacitance is about 0.5 pF, and rise time is 0.4 nsec.

### F. Transistor Testing

The  $f_T$  test equipment is being modernized by incorporating a solid state IF amplifier and new signal generators. Device evaluation to 10 GHz should be possible.

An attempt is being made to extract  $r_b'$  and  $r_b''$  from  $h_{rb}$  measurements. The technique involves multiple measurements and considerable computer processing.

## COMPUTER SYSTEMS

## GROUP 28

Two significant hardware installations were complete during this quarter - a performance upgrade of the IBM 3168 Model 1 central processing unit (CPU), and a second IBM 3705 Communications Controller. The CPU upgrade provided the performance improvement features equivalent to a conversion to a 3168 Model 3. Specifically, the high-speed buffer was doubled in size to a new capacity of 32K bytes and the average processing speed of the CPU was increased by some 5 to 10 percent. The second communications controller provided 32 additional ports to interface remote devices.

As previously reported, the growth in demand for remote device connections involves complex hardware, software, and cost considerations. One issue of major importance is that of addressing. In the 370/168 system, a single input/output channel is capable of addressing up to 256 unique devices. Since the channel on which the communications controllers are installed commits 80 addresses to other devices, only 176 are available for remote devices. This limit has already been reached, and the demand continues. While it would be possible to install another channel as well as other communications controllers, the cost would be high. A better solution seems to be a switching system that takes advantage of the fact that less than half of the 200 or more remote devices connected to the computer are active at any one time.

This concept is, of course, familiar in the form of voice or data telephone switching systems. Since most remote devices at Lincoln Laboratory are connected to the computer by direct wire, the switching function would have to be implemented by software. Such a "Channel Switchboard" has been developed for the 3705 Controller. It assigns channel addresses to a remote device communications line on an as-needed basis rather than on a fixed basis. That is, an available channel address is associated with a particular remote device line only when that line is activated by a user. The association is ad hoc, varying from one session to the next, depending on the total pattern of activity for all users. The Channel Switchboard is a modification of the standard IBM 3705 Emulation Program. It is currently in its final test stage and is scheduled for installation early next quarter. When completed, it will be capable of distributing 176 active channel addresses among a population of 510 remote devices.

The number and location of disk resident VS Batch Processing System data sets were significantly altered. The purpose was to reduce duplication and standardize operating procedures in the four different environments: VS in native mode, VS in classified mode, VS as a public batch facility under the VM time-sharing system, and VS as a private operating system on individual virtual machines under VM. The new organization permits convenient access to most system data sets for updating and testing during the day, thus considerably reducing the maintenance effort.

SOLID STATE  
DIVISION 8

INTRODUCTION

This section of the report summarizes progress during the period 1 May through 31 July 1977. The Solid State Research Report for the same period describes the work of Division 8 in more detail. Funding is primarily provided by the Air Force, with additional support provided by the Army, ARPA, NSF, and ERDA.

A. L. McWhorter  
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I. Melngailis  
Associate Head

DIVISION 8 REPORTS  
ON ADVANCED ELECTRONIC TECHNOLOGY

15 May through 15 August 1977

PUBLISHED REPORTS

Journal Articles

JA No.

4496	Applications of Infrared Lasers to Spectroscopy	A. H. M. Ross* P. L. Kelley K. W. Nill*	In <u>Frontiers in Laser Spectroscopy</u> , Vol. 2, edited by R. Balian, S. Haroche, and S. Liberman (North-Holland, Amsterdam, 1977), pp. 571-635
4677	Submillimeter Heterodyne Detection with Planar GaAs Schottky-Barrier Diodes	R. A. Murphy C. O. Bozler C. D. Parker H. R. Fetterman P. E. Tannenwald B. J. Clifton J. P. Donnelly W. T. Lindley	IEEE Trans. Microwave Theory Tech. <u>MTT-25</u> , 494 (1977)
4708	Schottky-Barrier Diodes for Submillimeter Heterodyne Detection	B. J. Clifton	IEEE Trans. Microwave Theory Tech. <u>MTT-25</u> , 457 (1977)
4709	Selective Black Absorbers Using rf-Sputtered $\text{Cr}_2\text{O}_3/\text{Cr}$ Cermet Films	J. C. C. Fan S. A. Spura	Appl. Phys. Lett. <u>30</u> , 511 (1977)
4718	$\text{Ag}_2\text{Se}-\text{Ga}_2\text{Se}_3$ Pseudobinary Phase Diagram	J. C. Mikkelsen, Jr.	Mater. Res. Bull. <u>12</u> , 497 (1977)
4721	cw Operation of Distributed Feedback $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$ Lasers	J. N. Walpole A. R. Calawa S. R. Chinn S. H. Groves T. C. Harman	Appl. Phys. Lett. <u>30</u> , 524 (1977)
4722	Polarised Infrared Reflectivity of $\text{CdGeAs}_2$	G. D. Holah* A. Miller* W. D. Dunnett* G. W. Iseler	Solid State Commun. <u>23</u> , 75 (1977)
4726	Thin-Film $\text{VO}_2$ Submillimeter-Wave Modulators and Polarizers	J. C. C. Fan H. R. Fetterman F. J. Bachner P. M. Zavracky C. D. Parker	Appl. Phys. Lett. <u>31</u> , 11 (1977)

\* Author not at Lincoln Laboratory.

JA No.

4728	Flash-Lamp-Excited NdP <sub>5</sub> O <sub>14</sub> Laser	S. R. Chinn W. K. Zwicker*	Appl. Phys. Lett. <u>31</u> , 178 (1977)
4734	Optoacoustic Measurements of Energy Absorption in CO <sub>2</sub> TEA-Laser-Excited SF <sub>6</sub> at 293 and 145 K	T. F. Deutsch	Opt. Lett. <u>1</u> , 25 (1977)
4737	High-Resolution Transient-Double-Resonance Spectroscopy in SF <sub>6</sub>	P. F. Moulton D. M. Larsen J. N. Walpole A. Mooradian	Opt. Lett. <u>1</u> , 51 (1977)
4743	GaAs Directional-Coupler Switch with Stepped $\Delta\beta$ Reversal	F. J. Leonberger C. O. Bozler	Appl. Phys. Lett. <u>31</u> , 223 (1977)

Meeting SpeechesMS No.

4140B	Decomposition of Water Using Solar Energy	J. G. Mavroides	Proc. Symp. and Workshop on the 5 MWt Solar Thermal Test Facility, Houston, Texas, 17-19 May 1976, p. 225
4230A	In <sub>1-x</sub> Ga <sub>x</sub> As <sub>y</sub> P <sub>1-y</sub> -InP Double-Heterostructure Lasers	J. A. Rossi J. J. Hsieh J. P. Donnelly	Chapter 6 in <u>Gallium Arsenide and Related Compounds</u> (St. Louis) 1976, edited by L. F. Eastman (The Institute of Physics, London, 1977), pp. 303-310
4261	Studies of Surface Defects on TiO <sub>2</sub> : Two-Dimensional Surface Phases	V. E. Henrich G. Dresselhaus H. J. Zeiger	In <u>Physics of Semiconductors</u> (North-Holland, Amsterdam, 1977), p. 726
4263	Theory of Resonant Raman Scattering in Europium Chalcogenides	S. A. Safran* G. Dresselhaus M. S. Dresselhaus* B. Lax*	Physica <u>89B</u> , 229 (1977)
4295	Thickness of InP Layers Grown by LPE from Supercooled Solutions	J. J. Hsieh	Chapter 2 in <u>Gallium Arsenide and Related Compounds</u> (St. Louis) 1976, edited by L. F. Eastman (The Institute of Physics, London, 1977), p. 74
4296	Ion Implanted Lo-Hi-Lo Annular GaAs IMPATT Diodes	R. A. Murphy C. O. Bozler J. P. Donnelly R. W. Laton G. A. Lincoln R. W. Sudbury W. T. Lindley L. Lowe* M. Deane*	Chapter 4 in <u>Gallium Arsenide and Related Compounds</u> (St. Louis) 1976, edited by L. F. Eastman (The Institute of Physics, London, 1977), p. 210

\* Author not at Lincoln Laboratory.

MS No.

4298	Conditions for Lattice-Matching in the LPE Growth of GaInAsP Layers on InP Substrates	J. J. Hsieh M. C. Finn J. A. Rossi	Chapter 1 in <u>Gallium Arsenide and Related Compounds</u> (St. Louis) 1976, edited by L. F. Eastman (The Institute of Physics, London, 1977), p. 37
4302	Ion Implantation in GaAs	J. P. Donnelly	Chapter 4 in <u>Gallium Arsenide and Related Compounds</u> (St. Louis) 1976, edited by L. F. Eastman (The Institute of Physics, London, 1977), p. 166

\* \* \* \*

UNPUBLISHED REPORTS

Journal Articles

JA No.

4710	Micro Fresnel Zone Plates for Coded Imaging Applications	N. M. Ceglio* H. I. Smith	Accepted by J. Appl. Phys.
4738	Analysis of the $4 \mu\text{m} \nu_1 + \nu_3$ Combination Band of $\text{SO}_2$	A. S. Pine G. F. Dresselhaus B. J. Palm R. W. Davies* S. A. Clough*	Accepted by J. Mol. Spectrosc.
4741	Phase Studies, Crystal Growth, and Optical Properties of $\text{CdGe}(\text{As}_{1-x}\text{P}_x)_2$ and $\text{AgGa}(\text{Se}_{1-x}\text{S}_x)_2$ Solid Solutions	J. C. Mikkelsen, Jr. H. Kildal	Accepted by J. Appl. Phys.
4744	Vibrational Two-Photon Resonance Linewidths in Liquid Media	S. R. J. Brueck	Accepted by Chem. Phys. Lett.
4745	Proton Bombardment in InP	J. P. Donnelly C. E. Hurwitz	Accepted by Solid-State Electron.
4748	310-MHz SAW Resonator with $Q$ at the Material Limit	R. C. M. Li	Accepted by Appl. Phys. Lett.
4751	Vibrational Energy Relaxation of $\text{CH}_3\text{F}$ Dissolved in Liquid $\text{O}_2$ and Ar	S. R. J. Brueck T. F. Deutsch R. M. Osgood, Jr.	Accepted by Chem. Phys. Lett.
4752	Ion Implanted n- and p-Type Layers in InP	J. P. Donnelly C. E. Hurwitz	Accepted by Appl. Phys. Lett.

\* Author not at Lincoln Laboratory.

JA No.

4753	Surface Relief Gratings of 3200-Å Period - Fabrication and Influence on Thin-Film Growth	D. C. Flanders H. I. Smith	Accepted by J. Vac. Sci. Technol.
4756	Thermal Expansion and Seeded Bridgman Growth of AgGaSe <sub>2</sub>	G. W. Iseler	Accepted by J. Cryst. Growth
4761	High Sensitivity Infrared Heterodyne Radiometer Using a Tunable Diode Laser Local Oscillator	R. T. Ku D. L. Spears	Accepted by Opt. Lett.
4766	A New Interferometric Alignment Technique	D. C. Flanders H. I. Smith S. A. Austin*	Accepted by Appl. Phys. Lett.

Meeting Speeches<sup>†</sup>MS No.

4177	Wavelength-Selective Surfaces for Solar Energy Utilization	J. C. C. Fan	Solar Energy Seminar, University of California, Berkeley, 3 June 1977
4270A	Photoemission and Energy-Loss Spectroscopy of Surface States on Metal Oxides	V. E. Henrich	Oak Ridge National Laboratory, Oak Ridge, Tennessee, 23 May 1977
4335A	Planar Schottky Barrier Diodes for Millimeter and Submillimeter Wave Applications	B. J. Clifton	Solid State Millimeter Wave Technology Workshop, San Diego, 24 June 1977
4335B	Submillimeter Wave Schottky Barrier Diodes for Heterodyne Detection	B. J. Clifton	University of California, Berkeley, 1 July 1977
4361	GaInAsP/InP Double-Heterostructure Lasers for Fiber Optic Communications	J. J. Hsieh	33rd Avionics Panel Meeting "Optic Fibers, Integrated Optics & Their Military Applications," London, UK, 16-20 May 1977
4392	Tunable Infrared Lasers	A. Mooradian	3rd Intl. Conf. on Lasers and Applications, Dresden, Germany, 28 March - 2 April 1977
4394	High-Sensitivity Heterodyne Radiometer Using a Tunable Diode Laser Local Oscillator	R. T. Ku D. L. Spears	1977 Conf. on Laser Engineering and Applications, Washington, DC, 1-3 June 1977
4405	Efficient Infrared Third-Harmonic Generation in Cryogenic Liquids	H. Kildal S. R. J. Brueck	

\* Author not at Lincoln Laboratory.

† Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

MS No.

4409	Line Tunable, Optically Pumped 16 $\mu$ m CO <sub>2</sub> Laser	R. M. Osgood, Jr.	1977 Conf. on Laser Engineering and Applications, Washington, DC, 1-3 June 1977
4468	Flash-Lamp Excited NdP <sub>5</sub> O <sub>14</sub> Laser	S. R. Chinn W. K. Zwicker*	
4516	Diode Lasers at 1.0 to 1.3 $\mu$ m for Optical Fiber Communications	I. Melngailis	
4431	Single Crystal Growth of Nd <sub>x</sub> (La, Y) <sub>1-x</sub> P <sub>5</sub> O <sub>14</sub>	W. K. Zwicker* T. Kovats* S. R. Chinn	5th Int'l. Conf. on Crystal Growth, Boston, 17-22 July 1977
4433	Growth of Ni-Doped MgF Crystals in Self-Sealing Graphite Crucibles	T. B. Reed R. E. Fahey P. F. Moulton	
4436	Photoemission Studies of Molecular Adsorption on Oxide Surfaces	V. E. Henrich	
4437	A New Interferometric Technique for Multiple-Mask Alignment	S. A. Austin* D. C. Flanders H. I. Smith	Inelastic Tunneling Conf. and Symp., University of Missouri, Columbia, 25-27 May 1977
4438	Polyimide Membrane X-Ray Lithography Masks - Fabrication and Distortion Measurements	D. C. Flanders H. I. Smith	
4439	X-Ray Lithographic and Processing Technologies for Fabricating Surface Relief Gratings with Profile Control < 400 $\text{\AA}$	D. C. Flanders H. I. Smith	
4437A	A New Interferometric Technique for X-Ray Mask Alignment	S. A. Austin* D. C. Flanders H. I. Smith	Intl. Conf. on Microlithography, Paris, France, 21-24 June 1977
4449	MBE Homostructure PbTe Diode Lasers with CW Operation Up to 100 K	J. N. Walpole S. H. Groves T. C. Harman	35th Device Research Conf., Cornell University, Ithaca, New York, 27-29 June 1977
4453	Ion Implantation in InP	J. P. Donnelly C. E. Hurwitz	
4479	GaAs Directional-Coupler Switch with Stepped $\Delta\beta$ Reversal	F. J. Leonberger C. O. Bozler	

\* Author not at Lincoln Laboratory.

MS No.

4480	Gap-Coupled Schottky-Diode/ LiNbO <sub>3</sub> Acoustoelectric Integrating Correlator	R. W. Ralston D. H. Hurlburt F. J. Leonberger J. H. Cafarella E. Stern	35th Device Research Conf. Cornell University, Ithaca, New York, 27-29 June 1977
4523	A Bipolar NPN Transistor with Reduced Low Current $\beta$ Falloff	G. L. Hansell C. G. Fonstad*	
4469	Optically Pumped 16 $\mu\text{m}$ CO <sub>2</sub> Laser	R. M. Osgood, Jr.	Lasers for Isotope Separation Conf., Albuquerque, New Mexico, 17-19 May 1977
4502	Lasers at 1.0 - 1.3 $\mu\text{m}$ for Optical Fiber Communications	I. Melngailis	1977 Intl. Conf. on Integrated Optics and Optical Fiber Communications, Tokyo, Japan, 18-20 July 1977
4508	Preparation and Properties of MgO/Au and Cr <sub>2</sub> O <sub>3</sub> /Cr Multi-phase Films	J. C. C. Fan	New England Symp. of American Vacuum Society, Burlington, Massachusetts, 16 June 1977
4510	Molecular Beam Epitaxial Growth of Thin Semiconductor Films	A. R. Calawa	
4516A	Diode Lasers at 1.0 to 1.3 $\mu\text{m}$ for Optical Fiber Communications	I. Melngailis	NSF Grantee-USER Mtg. on Optical Communications, New York, 6-7 June 1977
4530	IR Spectroscopy via Difference-Frequency Generation	A. S. Pine	3rd Intl. Conf. on Laser Spectroscopy, Jackson, Wyoming, 5-8 July 1977
4535	Advantages and Fabrication of Two-Sided GaAs Power FETs	R. A. Murphy	GaAs FET Applications Workshop, San Diego, 24 June 1977
4537	Vibrational Energy Transfer Processes in Simple Cryogenic Liquids	S. R. J. Brueck R. M. Osgood, Jr. T. F. Deutsch	Gordon Conf. on Molecular Energy Transfer, Wolfeboro, New Hampshire, 11-15 July 1977
4538	Double Resonance Measurements of $\nu_3$ Mode Kinetics of SF <sub>6</sub> Under Intense CO <sub>2</sub> TEA Laser Excitation	T. F. Deutsch S. R. J. Brueck	
4558	Efficient Infrared Four-Wave Processes in Cryogenic Liquid Mixtures	H. Kildal S. R. J. Brueck	Gordon Res. Conf. on Non-linear Optics, Plymouth, New Hampshire, 15-19 August 1977

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SOLID STATE  
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

The characteristics of CW double-heterostructure GaInAsP diode lasers, which had an emission wavelength of 1.22  $\mu\text{m}$  at 22°C, are reported for heat-sink temperatures up to 50°C. The temperature dependence of the threshold current density for pulsed operation follows the exponential function  $J_{\text{th}} \propto \exp [T/T_o]$ , where  $T_o \sim 75^\circ\text{C}$ .

The previously reported GaAs stepped  $\Delta\beta$ -reversal electrooptic waveguide switch has been substantially improved. By biasing the electrodes independently, the power isolation at 1.06  $\mu\text{m}$  could be enhanced to 25 dB in each switch state. When considered as a modulator, this device has a calculated power-bandwidth ratio in a 50- $\Omega$  system of 40 mW/MHz.

The wavelength dependence of GaAs  $p^+ - n^+$  directional couplers and electrooptic switches has been determined in the range 0.92 to 1.15  $\mu\text{m}$ . It has been found that the coupling length varies faster than inversely with wavelength.

InP has been doped by ion implantation with several ions to yield layers of both n- and p-type conductivity.  $\text{Se}^+$  and  $\text{Si}^+$  were found to be efficient n-type dopants with activations in excess of 75 percent.  $\text{Cd}^+$ ,  $\text{Mg}^+$ , and  $\text{Be}^+$  were all acceptors, with  $\text{Mg}^+$  yielding a sheet hole concentration as high as  $5 \times 10^{13} \text{ cm}^{-2}$  for a dose of  $1 \times 10^{14} \text{ cm}^{-2}$  at 150 keV.

II. QUANTUM ELECTRONICS

The characteristics of a passively Q-switched, flash-lamp-excited  $\text{NdP}_5\text{O}_{14}$  laser have been studied as a function of Q-switch dye concentration and output mirror transmission. Up to 2 mJ in a 6-nsec pulse have been obtained with 1-J energy into the lamp.

Using high-optical-quality material grown at Lincoln Laboratory, laser operation at 1.63  $\mu\text{m}$  has been observed in  $\text{MgF}_2:\text{Ni}$ . Lasers of this type, which operate using phonon-assisted electronic transitions, provide a new source of broadly tunable radiation in the near-infrared, and may be efficiently optically pumped by a Nd:YAG laser.

An atmospheric pressure mini-TEA  $\text{CO}_2$  laser has been designed and constructed. Arc-free pulse energies of 30 mJ and repetition rates over 10 Hz have been obtained with the initial unit.

Studies have been continued on third-harmonic generation (THG) of  $\text{CO}_2$  laser radiation in cryogenic liquid CO mixtures. A THG power-conversion efficiency of 2 percent has been obtained using a 100-nsec pump laser pulse length.

Raman scattering measurements of the vibrational frequency and linewidth of liquid  $\text{CO-O}_2$ ,  $\text{CO-N}_2$ , and  $\text{CO-Ar}$  mixtures have been carried out. The dipolar broadening due to CO-CO interactions has been shown to dominate the linewidth for high CO concentrations.

Infrared double-resonance measurements have been performed on  $\text{CO}_2$  TEA-laser-excited  $\text{SF}_6$ . A pressure-independent induced-absorption signal, which may be due to a coherent excitation process, is observed. Induced-absorption spectra, obtained as a function time after the excitation pulse, provide information on the flow of energy in the molecule.

### III. MATERIALS RESEARCH

A study has been made of the effect of  $O_2$  partial pressure during deposition on the electrical and optical properties of Sn-doped  $In_2O_3$  films obtained by rf sputtering. Close control of the  $O_2$  pressure was found to be essential for the reproducible preparation of high-quality films for use as transparent conductors in optoelectronic devices.

The interaction of  $H_2O$  with surfaces of  $TiO_2$  and  $SrTiO_3$ , two materials that have been successfully used as catalytic electrodes in the photoelectrolysis of  $H_2O$  to produce  $H_2$  and  $O_2$ , has been investigated by ultraviolet photoemission spectroscopy in ultrahigh vacuum. For low exposures to  $H_2O$  vapor, the data for  $TiO_2(110)$  surfaces indicate the presence of OH radicals produced by dissociative chemisorption of  $H_2O$ ; for  $TiO_2(110)$  surfaces at high exposures and for  $SrTiO_3(100)$  surfaces at all exposures, the chemisorption of  $H_2O$  is nondissociative, but some of the molecular orbitals are shifted in energy with respect to those of the gaseous  $H_2O$  molecule.

In a continuing effort to identify new solid electrolytes for use in high-energy-density secondary batteries, it has been found that  $Na_5YSi_4O_{12}$  exhibits high  $Na^+$ -ion conductivity. For a ceramic rod with 92 percent of theoretical density, the conductivity at  $300^\circ C$  is  $\sim 0.1 \Omega^{-1} cm^{-1}$ , compared with  $\sim 0.4 \Omega^{-1} cm^{-1}$  for  $\beta$ -alumina and NASICON.

### IV. MICROELECTRONICS

High-efficiency GaAs single-crystal solar cells have been fabricated utilizing a homojunction formed by chemical vapor deposition of a thin  $n^+$  layer on a thicker  $p$  layer. Conversion efficiencies of 15.3 percent (17 percent when corrected for contact area) at AM 1 (unity air mass) have been achieved without the use of  $Ga_{1-x}Al_xAs/GaAs$  heterostructures. These conversion efficiencies are approaching those obtained with heterostructure cells, and are considerably higher than those previously reported for GaAs homojunction devices.

A surface-oriented GaAs Schottky-barrier mixer diode has been used to harmonically mix the 82nd harmonic of an X-band klystron with a 761-GHz submillimeter laser signal. Two methods have been used to couple radiation to the diode. In the first, the surface-oriented diode is connected to a quartz stripline filter structure which is suspended across an overmoded, reduced-height N guide. The second method utilizes integrally connected half-wavelength dipole antennas to enhance the coupling.

A grating mask consisting of  $0.635\text{-}\mu m$  lines and spaces has been fabricated with conventional mask-making apparatus. This resolution (788 line pairs/mm) is 2X greater than the stated optimized specifications for the equipment, and was achieved by precise processing procedures and by a double-reduction technique utilizing 100X reticles and photocomposition of 10X reticles and the final mask. The need for a double-wide space in the center of four of the final gratings represented a major challenge for the pattern generation of the 100X reticle and the photocomposition of the 10X reticle.

### V. SURFACE-WAVE TECHNOLOGY

The combination of a new design approach and a simple fabrication procedure has led to the first realization of a practical surface-acoustic-wave two-port resonator with  $Q$  at the material limit. In particular, the device on ST quartz exhibited an unloaded  $Q$  in excess of 32,000 when operated in vacuum at 310 MHz. The latter value of  $Q$  is virtually the same as the best

estimate of the material Q at this frequency, which implies that all losses in the system have been rendered negligible in comparison with the intrinsic propagation loss in the material.

A new interferometric alignment technique has been developed that is suitable for aligning x-ray-lithography masks or photomasks relative to a substrate. A superposition precision of 200 Å has been demonstrated and, in principle, better than 100 Å should be possible. The superposition of matching grating-type alignment marks on facing plates is determined from the intensities of beams multiply diffracted from the matching alignment marks.

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